PROCEEDINGS OF SCIENCE

Bilinear R-Parity Violation at the ILC – Neutrino Physics at Colliders

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Supersymmetry (SUSY) with bilinearly broken R parity (bRPV) offers an attractive possibility to explain the origin of neutrino masses and mixings. In such scenarios, the study of neutralino decays at colliders gives access to neutrino sector parameters.
The ILC offers a very clean environment to study the neutralino properties as well as its subsequent decays, which typically involve a W or Z boson and a lepton. This study is based on ILC beam parameters according to the Technical Design Report for a center of mass energy of 500 GeV. A full detector simulation of the International Large Detector (ILD) was performed for all Standard Model backgrounds and for neutralino pair production at one example model point. The bRPV parameters are fixed according to current neutrino data.
In this scenario, the $\tilde{\chi}_1^0$ mass can be reconstructed with an uncertainty of about 0.1% for an integrated luminosity of 100 fb^{-1} from direct $\tilde{\chi}_1^0$ pair production, thus, to a large extent independently of the rest of the SUSY spectrum. The achievable precision on the atmospheric neutrino mixing angle $\sin^2\theta_{23}$ from measuring the neutralino branching fractions BR($\tilde{\chi}_1^0 \to W\mu$) and BR($\tilde{\chi}_1^0 \to W\tau$) at the ILC is comparable to current uncertainties from neutrino experiments. Thus, the ILC could have the opportunity to unveil the mechanism of neutrino mass generation.

The European Physical Society Conference on High Energy Physics -EPS-HEP2013
18-24 July 2013
Stockholm, Sweden

*Speaker.

PoS(EPS-HEP 2013)034

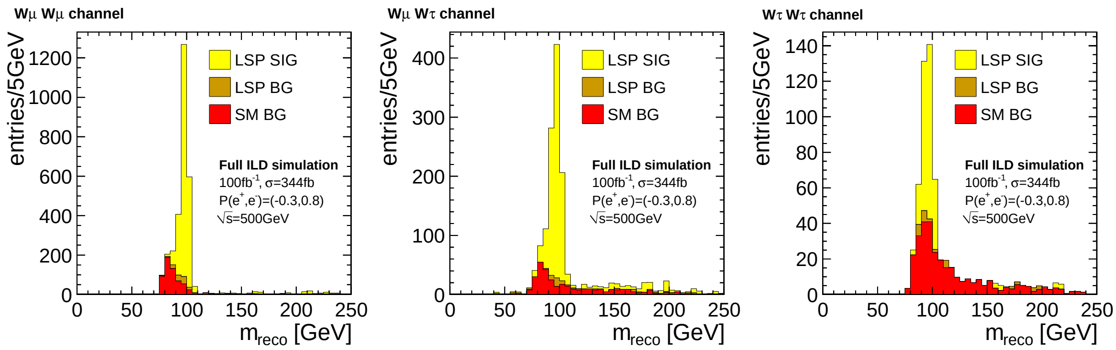

Figure 1: Mass reconstruction of the LSP in the different event classes.

1. Introduction

Supersymmetry (SUSY) with bilinearly broken R parity (bRPV) is an attractive extension to the Standard Model (SM). Compared to R parity conserving SUSY, bRPV introduces six additional free parameters, which can be adjusted in order to describe neutrino phenomenology consistently. As a consequence of RPV the lightest SUSY particle is no longer stable and decays into Standard Model particles. As shown in [1], the ratios of branching ratios of neutralino decays are related to the neutrino mixing angle $\tan^2\theta_{23} \simeq \mathrm{BR}(\tilde{\chi}_1^0 \to W\mu)/\mathrm{BR}(\tilde{\chi}_1^0 \to W\tau)$ and, thus, neutrino properties can be studied at colliders in this model.

In the presented analysis we examine the achievable precision in measuring the ratio of the branching ratios for the International Large Detector concept (ILD) [2], which is one of two proposed experiments at the International Linear Collider (ILC). The analysis is based on a GEANT4-based detector simulation of the ILD taking into account realistic ILC beam parameters.

2. Analysis strategy

At the ILC, Bino-like neutralinos are most efficiently produced in direct pair production for selectron masses of up to a few TeV. In order to measure the ratio of branching ratios, we define three event classes named after the leptons originating from the two neutralino decays in addition to the two W bosons ($\mu\mu$, $\mu\tau$, $\tau\tau$). Considering only events with hadronically decaying W bosons, a signal event is fully reconstructable with six visible fermions in the final state (LSP SIG). All other, non-signal-like neutralino decays are treated as background (LSP BG).

Those events, which fulfil a six final state topology are tested against the three event classes. Hereby, it is required to find two good on-shell W candidates from four objects. Adding the fifth and sixth object to the first and second W-candidate has to reconstruct to the same mass in order to form good neutralino candidates. The number of muons in the event is used to discriminate between the event classes. Finally, the different hypotheses are distinguished based on a χ^2 test.

For more details on this analysis including a detailed description of the event selection, the interested reader is referred to Ref. [3]. The resulting distributions of reconstructed masses of neutralino candidates including full SM background (SM BG) are shown in Figure 1.

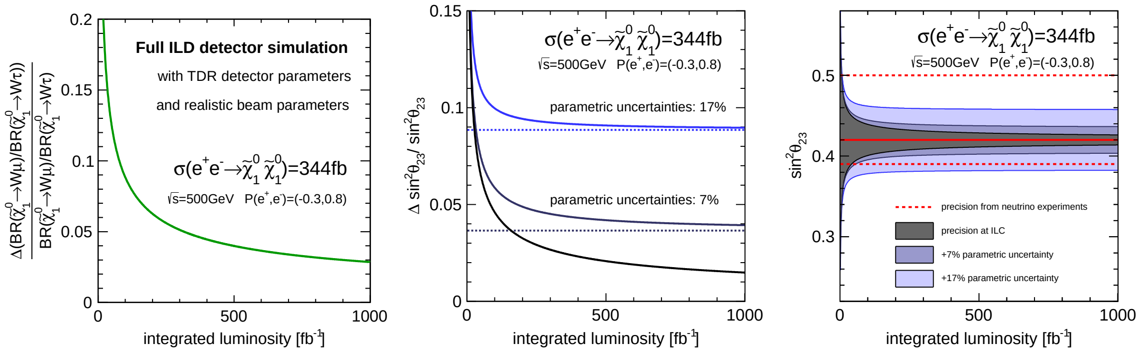

Figure 2: Precision of the measurement of $\mathrm{BR}(\tilde{\chi}_1^0 \to W\mu)/\mathrm{BR}(\tilde{\chi}_1^0 \to W\tau)$ (left) and the atmospheric mixing angle $\sin^2\theta_{23}$ (middle). The achievable precision is in the range of current neutrino experiments (right).

3. Results

The $\mu\mu$ class has a very clear signal peak, which can be employed for measuring the LSP mass very precisely. After SM background subtraction and a fit of a Gaussian to the the distribution one obtains for the mass $m^{\mathrm{fit}}_{\tilde{\chi}_1^0} = (98.40 \pm 0.10(\mathrm{stat.}))\,\mathrm{GeV}$. The measured value is within the error in very good agreement with the input mass $m^{\mathrm{input}}_{\tilde{\chi}_1^0} = 98.48\,\mathrm{GeV}$ of the studied example point.

This precision measurement of the LSP mass in the $\mu\mu$ channel is used to define a signal region $m^{\mathrm{fit}}_{\tilde{\chi}_1^0} \pm 10$ GeV, which helps to further increase the selection purity in the event classes. From Monte-Carlo simulation determined selection efficiencies and purities are used to calculate the number of real events per event class. Because of the low selection purity in the $\tau\tau$ channel, only the $\mu\tau$ and $\mu\mu$ channel are considered for determining the ratio of branching ratios. The uncertainty on the ratio of $N^{\mathrm{true}}_{\mu\mu}$ and $N^{\mathrm{true}}_{\mu\tau}$ accounts for Poissonian BG fluctuations as well as Poissonian fluctuations in the number of measured events in the event classes. Finally we determine the resulting statistical uncertainty for the studied parameter point and an integrated luminosity of 100 fb^{-1} to about 9% (cf. Fig. 2 (left)). This scales down to roughly 4% for 500 fb^{-1}, which corresponds to two years of full ILC running at 500 GeV. The uncertainty of the measured ratio of branching ratios can be translated into an uncertainty of the atmospheric mixing angle. The given relation is only an approximation and there exist additional parametric uncertainties coming from residual SUSY parameter dependencies. Two scenarios for the parametric uncertainty are shown in Fig. 2 (middle), in which different assumption on the kinematically accessible SUSY particles at the ILC are made. The comparison of the estimated precision at the ILC with the precision of current neutrino experiments shows that ILC can test, if neutrino mixing and mass generation is introduced by RPV (cf. Fig. 2 (right)).

References

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